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AN APPLICATION OF SPANS TECHNOLOGY TO TOXIC CONTAMINANT MONITORING IN THE ATLANTIC REGION

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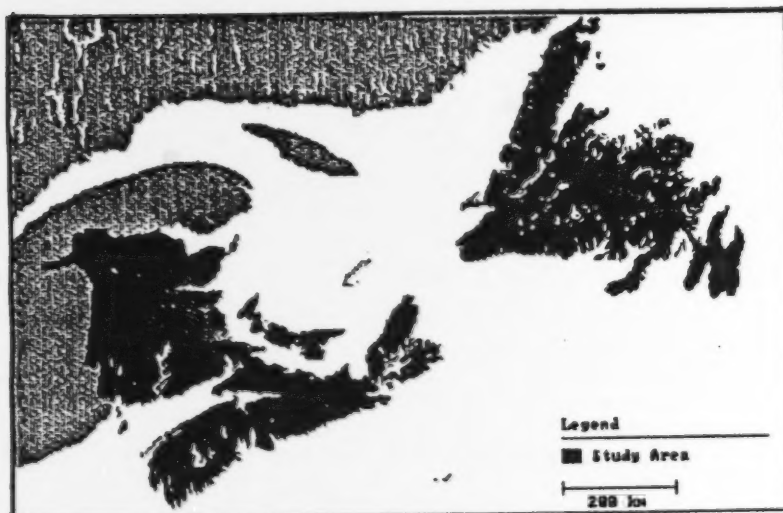
Canada

INLAND WATERS DIRECTORATE
ATLANTIC REGION
WATER QUALITY BRANCH
MONCTON, NEW BRUNSWICK

AN APPLICATION OF SPANS TECHNOLOGY

TO TOXIC CONTAMINANT MONITORING

IN THE ATLANTIC REGION



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EXECUTIVE SUMMARY

The presence of toxic organic chemicals in the water, bottom sediments and biota of the Atlantic Region has attracted increasing concern. Most environmental contamination is either a direct result of, or enhanced by, anthropogenic activity. It was felt that land use data could be used to identify areas of potential pesticide and contaminant input, as the presence of certain factors in an area will increase the potential for higher levels of contaminants. By identifying the areas in which these factors are present, one may infer the existence of possibly higher toxic chemical loads. Previously, however, land activity information has not been readily accessible to water resource managers and investigators. The objectives of this study were to: identify and rank areas of potential anthropogenic sources of contaminants based on land use data, to verify the resultant potential areas by use of existing Water Quality Branch data, and to illustrate how such information could be used during the design of monitoring programs and in site prioritization.

To accomplish these tasks all relevant data sets were obtained from the Canada Land Data System of Environment Canada. The micro-computer based SPANSTM geographic information system was used to conjugate land use information such as forestry use and capability, agricultural use and capability, and population density. Two principal hypothesis maps were generated through the conjugation of land use data, industrial location and demographic data bases. The Potential Sources of Pesticides map illustrates the potential sources of agricultural pesticides while the Potential Sources of Toxics map illustrates the combination of agricultural, industrial and population factors. A relative scale was employed to rank regional contaminant potential on a "Low" to "Very High"

basis. An areal analysis of the toxics map indicated that approximately 10 percent of the region fell into the two highest categories.

Water Quality Branch toxic chemical program data confirmed the accuracy of this map. Where Branch data indicated elevated contaminant levels, 78 percent of these observations were in the two highest areas on the hypothesis map. Additionally, a strong correlation between the potential pesticide map and observed nutrient levels supported the validity of the hypothesis maps.

Such information can assist water resource managers to plan monitoring projects, prioritize site selection, and identify "hot spots". The ability to conjugate various data bases opens up areas of investigation that were previously difficult. The inclusion of geological, hydrological and biological data, land fill sites, secondary industry, and atmospheric information, will facilitate greater ecosystem understanding, by allowing the modelling of various processes and inter-relationships.

ABSTRACT

Two maps were generated through the conjugation of land use, land capability, industrial location, and demographic data bases. The Potential Sources of Pesticides map illustrates the potential sources of agricultural pesticides, while the Potential Sources of Toxics map illustrates known agricultural, industrial, and population factors. A relative scale ranging from "Very High" potential to "Low" potential was employed to rank contaminant potential on a regional scale. An areal analysis of this map indicates that approximately 10 percent of the region fell into the "Very High" and "High" categories.

An examination of empirical data confirms the general accuracy of this map. Of the 55 observations of toxic contaminants (PAH including Fluoranthene, DDT, and PCB) ranked "High" and "Very High", 78% (43) are located in areas ranked "High" and "Very High" on the hypothesis map. Additionally, a strong correlation between potential pesticide input and nutrient levels supports the validity of the hypothesis map.

Monitoring networks for individual toxic contaminants may be enhanced by following the approach of this study. The occurrence of a toxic chemical in the environment is a function of many factors, but by converting information relevant to a specific toxin (contributing industries, soil types, etc.) into maps and conjugating them together via matrix overlays, accurate predictive maps may be created. Making use of these maps (by identifying "hot-spots" etc.) will assist in selecting monitoring locations by eliminating some of the guesswork currently involved.

RÉSUMÉ

Deux cartes furent produites à partir de la conjugaison de banques de données concernant l'emploi des terres, la capacité de celles-ci, l'emplacement des industries et les informations démographiques. La carte des sources potentielles de pesticides illustre les sources potentielles de pesticides agricoles, tandis que la carte des sources potentielles de substances toxiques illustre des facteurs agricoles, industriels et démographiques connus. Une échelle relative allant d'un potentiel "très élevé" à un autre plus "faible" fut employée pour ordonner le potentiel de contamination sur une base régionale. Une analyse de l'aire de cette carte indique qu'approximativement 10% de la région tombe dans les catégories "très élevée" et "élevée".

Un examen des données empiriques confirme l'exactitude générale de cette carte. Parmi les 55 observations de contaminants toxiques (HAP incluant le fluoranthène, le DDT et les PCB), qui se classent dans les catégories "élevée" et "très élevée", 78% (43 observations) concernent des régions "élevées" et "très élevées" sur la carte des hypothèses. De plus, le fait qu'il existe une forte corrélation entre l'apport potentiel de pesticides et les niveaux de concentration des éléments nutritifs supporte la validité de la carte des hypothèses.

Les réseaux de surveillance pour chaque contaminant toxique peuvent être améliorés en suivant l'approche proposée dans cette étude. La présence d'un produit chimique toxique dans l'environnement dépend de plusieurs facteurs. Cependant, en convertissant les informations pertinentes d'une toxine spécifique (industries contributantes, types de sol, etc...) dans des cartes et en les conjuguant ensemble sous forme de

matrices de recouvrement, des cartes prédictives précises peuvent ainsi être créées. L'utilisation de ces cartes (par identification des "points chauds", etc...) aidera dans la sélection des stations de surveillance, en éliminant une partie de la conjecture habituellement impliquée.

INTRODUCTION

The rivers, streams, lakes and underground wells in the Atlantic Region contain a great quantity of fresh water that supports a multitude of domestic, agricultural, recreational and industrial activities, and also serves as an important source of aesthetic enjoyment. However, increasing stress placed on water reserves by these competing demands is becoming a significant concern.

Siltation, over-abundant nutrients and bacteria, acidic deposition, and toxic chemicals all pose a serious threat to the Atlantic freshwater system (Eaton *et al.*, 1986). Siltation is common to all four provinces, and is predominantly caused by logging, mining, agriculture, road building, and general construction. Aquatic invertebrates are smothered and spawning grounds are violated as sediment blankets the bottom of a water body. Another source of water quality degradation, excess nutrient and bacteria loads, enter freshwater systems via agricultural and, urban runoff, industrial outfalls, and municipal sewage. The resulting Biological Oxygen Demand (BOD) and accelerated eutrophication impair the potability of water, limit its recreational capabilities, and may adversely affect human health. Additionally, since much of the Atlantic Region is poorly buffered against an influx of sulphur and nitrogen oxides, the degenerating effects of acid rain on surface freshwater supplies are potentially disastrous. The long range transport of pollutants is illustrated by the presence of organochlorine pesticides and polyaromatic hydrocarbons in wet precipitation samples collected in the region (Brun, 1983, 1984, 1985). Also, known industrial point sources of toxic chemicals have been shown to be in proximity to habitats frequented by migratory bird populations (P. Lane and Associates, 1986).

The presence of toxic organic and inorganic chemicals in the freshwater, bottom sediment and biota of the Atlantic Region has attracted increased concern. Toxic chemicals are generally defined as substances which are resistant to natural degradation, tend to bioaccumulate in the tissues of organisms, may cause irreversible biological changes at low levels, and are often irretrievable once released into the environment. Examples of such substances include mercury, cadmium, lead, arsenic, polycyclical aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and DDT. Although heavy metals and PAH's may occur naturally, most toxins result from human activities. Agricultural herbicides and pesticides, and the disposal and storage of industrial waste, including leaks and spills, represent a significant toxic input to the environment. A recent survey identified over 1,500 potentially hazardous abandoned and active dump sites in the region, indicating the geographical extent of this problem (Eaton et al., 1986).

Environment Canada's involvement in toxic chemical research has been one of gradual evolution. The Great Lakes experience throughout the late 1960's initiated many scientific efforts in this area as for perhaps the first time in North American history, scientists were faced with the urgent need to investigate the environmental presence of only recently discovered toxic components. More accurate analytical instruments were developed to meet this challenge, and as a result, detection limits were lowered and more toxins were able to be identified. This trend continues still today. As technology evolves more precise tools, previously undetected toxins become identifiable, and the scope of study is widened further.

The Water Quality Branch has been active since 1965 in monitoring water quality in the Atlantic Region. Data has been obtained documenting major ion, heavy metal, pesticide

and environmental contaminant levels in the aquatic environment. The large amounts of water quality data generated necessitates the use of computers for data storage and manipulation. Previously, however, land activity information has not been easily accessible to water resource managers and investigators.

Most environmental contamination is either a direct result of (as in the use of agricultural insecticides), or enhanced by (as in the case of mining and road construction) anthropogenic activity. It was therefore felt that land use data could be used to identify areas of potential contaminant input throughout Atlantic Canada. This would, in turn, permit more effective monitoring of environmental contaminants.

In order to access and manipulate land use information contained in the Canada Land Data System (CLDS), a microcomputer-based software package (SPANS) was used.

The first water quality application of SPANS technology was undertaken by Howell et al. (1988) who applied SPANS to distinguish between local and transboundary acidification contributions affecting regional lakes. Subsequently, the Water Quality Branch, Atlantic Region and Inland Waters and Land Directorate, Ottawa undertook a brief assessment of SPANS as applied to toxic chemical data for the region. This project was assigned to a co-op student from the University of Waterloo. The ensuing report, (Hanna 1987), clearly illustrated that demographic and anthropogenic activity information could be related to observed levels of toxic chemicals in the Atlantic Region. As a result it was decided to build upon the work completed by Hanna (1987) and produce a Water Quality Branch document identifying applications of SPANS technology to the monitoring of toxic chemicals in the aquatic environment.

The objectives of this report are as follows: First, to identify and rank areas of potential anthropogenic sources of toxic contaminants throughout the Atlantic Region based on existing land use data. This involves the construction of a potential toxic sources hypothesis map by overlaying several land use maps. Second, to verify the hypothesis by correlating Water Quality Branch observed toxic chemical data and the predicted areas of anthropogenic sources of toxic contaminants. And last, to illustrate the use of this data base as a tool in the planning and construction of monitoring networks and in the prioritization of site selection.

METHODOLOGY

SPANS (Spatial Analysis System)

The performance of these tasks required extensive use of two commercially available software packages, namely: Spatial Analysis System (SPANS Version 3.6) marketed by Tydac Technologies Inc., and Dbase III+ produced by Ashton-Tate Inc. SPANS is a state-of-the-art micro-computer based Geographic Information System (GIS) which permits the analysis and modeling of spatial information. Traditionally, the integration of spatial data has been performed by manually transforming the spatial data sets to a common scale and projection, creating a transparent overlay for each data set, juxtaposing these overlays, and recording the relationships. The time and potential for error involved in this process has drastically reduced its utilization. SPANS permits these basic overlays and much more complicated modeling procedures to be executed in minutes and virtually error free. Dbase III+ is an industry-standard database management tool, and is used in conjunction with SPANS to input and manipulate various data sets. Since SPANS is relatively new and there are few documented applications, this report serves as a case study for SPANS applications to water quality data.

Data Sources and Preparation

The initial step involved the acquisition of all relevant data sets and their preparation for use in SPANS. The Canada Land Data System (CLDS) of Environment Canada is one of the largest repositories of spatial land use information in the world. As a result, most of the information required to generate the final hypothesis map resided in Ottawa. Seven rasterized maps were downloaded from the CLDS databank to form the foundation of this study. All subsequent maps resulted

from combinations of these maps, data generated by the Water Quality Branch, and data obtained from other agencies.

First, a political boundary map and shoreline map for the region were downloaded and overlaid in SPANS to define the study area. Next, an ecodistrict map was downloaded along with recolored agriculture and forestry use data. To enhance this information, land capability maps for agriculture and forestry collected by the Canada Land Inventory (CLI) were also brought into SPANS. Also, population data were imported from Statistics Canada based on Electoral Areas for the region.

Additionally, the latitude and longitude co-ordinates for 39 known industrial locations (P. Lane and Associates, 1986) and the Water Quality Branch observations were converted to database files (.dbf) using Dbase III+. Next, a sequential number was assigned to each of the records. These numbers are required because SPANS randomly rearranges the order of the input database file when generating its own point files (.pnt). Without a sequential number, it would be difficult to determine which observation level belonged to the appropriate metering location once in SPANS.

Following this, a Dbase III+ program was written to compute the median value for each contaminant at metering stations which recorded multiple observations. This program was run for each file containing contaminant observations, yielding one observation (the median) for each metering location and thereby reducing the number of records in each database file. The files were then subjected to another Dbase III+ program to convert the observed median levels of toxic substances from an interval to an ordinal scale. That is, each record in each file was assigned a ranking of "greater than detection limit" or "detection limit or less" based on its median observed toxic level. Table 1 contains a breakdown

of these rankings. The final step before bringing this information into SPANS was to create separate Standard Data Format (SDF) files (.dat) from each toxic substance Dbase file based on the assigned ranking. Additionally, the Dbase III+ file containing industrial point sources was also copied to a (.dat) file. This was necessary as SPANS will not accept as input a file in Dbase format.

Plotting the observed levels of contaminants and correlating them to the hypothesis map were the tasks entailed in the second stage of the project. The median values for each contaminant were plotted on separate maps.

Generation of the Hypothesis Map

It is generally accepted that the presence of certain factors in an area will increase the potential for higher levels of toxic contaminants. By identifying the areas in which these factors are prevalent, one may infer the existence of possibly high toxic chemical loads. This simple syllogism provided the rationale behind the creation of the hypothesis map entitled "Potential Sources of Toxics".

The benefits of a map which identifies areas more likely to contain or potentially contain high levels of toxic constituents is readily demonstrated. Most significantly, it may be used as a schematic to assist in the planning of an effective monitoring network. It may also be used as a predictive tool, an instrument to model the impacts of toxins in the environment. In either capacity, it functions as an excellent starting point for more rigorous studies of the dynamics of toxic chemicals in the Atlantic Region.

It is axiomatic that areas of intense agriculture, high population densities, and heavy industry are potential producers of various toxic substances. The activities

associated with agriculture, landfills and other waste handling facilities combined with higher populations, and the offal produced by mines, paper mills and refineries may contain pesticides, heavy metals and toxic environmental contaminants. Thus, for the purpose of this study, these represent the factors which were combined to create the hypothesis map. Figure 1 is a flowchart description of the overlays performed to generate the final hypothesis map.

The first two overlays were aimed at refining CLI agriculture and forestry use data. Agricultural use by ecodistrict and forestry use by ecodistrict data were refined by overlaying land capability for agriculture and forestry respectively. Thus, a much more accurate representation of land activity was provided. The matrix used to accomplish these overlays is provided in Table 2. Basically, areas characterized by high use and high capability (classes 2 through 4) were reclassified as "High Potential Use" and so on. The results of these two matrices are illustrated by the "Potential Forestry Use" and "Potential Agricultural Use" maps, Figures 2 and 3.

These two maps were then subsequently overlaid by means of another matrix, Table 3, which illustrates that areas high in agricultural use and low in forestry use received the highest potential rating for pesticide input. Thus, the generation of the "Potential Sources of Pesticides" map, Figure 4, was straightforward, and based solely upon land use and land potential.

In order to expand the hypothesis further, data as to landfills and industry were needed to encompass a broader range of contaminants. It was felt that population density could be used to estimate the potential for landfills, secondary manufacturing and home and garden use of various pesticides, fertilizers and a myriad of household products.

Data from Statistics Canada was imported to calculate population densities.

The 4,000 plus population centroids (a centroid is defined as that point on a plane which minimizes the weighted sum of the squared distances to all nodes - the centre of gravity of a distribution) provided by Statistics Canada for the Atlantic region presented too large a file for SPANS to manage. To circumvent this problem, a program which recomputed the centroid from Electoral Areas to Census Divisions was run for the population file, and the new file created was then imported to SPANS. By rolling the population data into Census Divisions (which are groupings of Electoral Areas), the point file was reduced to under 2,000 records.

To convert the points plotted by this procedure to areas, Thiessen Polygons were generated for each centroid. A Thiessen Polygon (or Voronoi diagram) defines a region for each point (X) such that the set of all points are closer to X than to any other point. A Voronoi diagram therefore assigns geographic areas to a set of point locations. Since the population data were to be overlayed with the land use information, this conversion from a point map to an area map was required.

The polygons in the resultant map were then recolored based on population density. To accomplish this, an area analysis was performed on the Voronoi map yielding area calculations for each centroid location. These area figures were then read into the Dbase file containing the population figures and the density for each centroid was computed using another simple Dbase program which divided population by area. As with the toxic chemical data, the raw results of this operation were then converted to an interval scale indicating high, moderate, and low population densities. The Voronoi

diagram was then recolored based on this ranking to produce a map entitled "Population Density".

To create the next map, "Potential Non-Industrial Sources", the population data was combined with the "Potential Sources of Pesticides" map by means of another matrix, Table 4. The use of this matrix further refined the areas identified as potential sources of toxic contaminants by including population densities with the potential sources of pesticides.

Adding industrial point sources data, Figure 5, obtained from P. Lane & Associates, (1986) was the last step in generating the hypothesis map. First, the point file created by SPANS when industrial locations were imported was divided and copied to two new data files (.dat). One file contained 35 locations which required twenty kilometre spheres of influence drawn around them, while the other file contained three industrial locations requiring forty kilometre spheres of influence. The size of the spheres was based upon the amount of industry with no special consideration for prevailing wind directions. Saint John, New Brunswick, Halifax and Sydney, Nova Scotia, were assigned larger spheres due to the amount of industrial activity associated with each location. To draw the spheres the Potential Mapping function (potmap.inp) of SPANS was invoked. The resulting two maps (one indicating 20 km spheres, the other indicating 40 km spheres) were then stamped on top of the "Potential Non-Industrial Sources" map to create the final hypothesis map, entitled "Potential Sources of Toxic Contaminants".

The Potential Sources of Toxic Contaminants map, Figure 6, represents the cumulative result of all overlays ranking potential input on a qualitative regional scale of highest to lowest potential.

Integrating Observed Toxic Chemical Data

Empirical data had to be compared to the potential map to ascertain if the hypothesis was sound. A significant amount of data has been generated by the Water Quality Branch, Atlantic Region, for the presence of pesticides, heavy metals, and environmental contaminants in surface water, sediments and biota of the region (O'Neill 1988). All observed toxic chemical data used for hypothesis testing was generated by the Water Quality Branch, Atlantic Region, and addressed four groupings for which a large number of samples existed: fluoranthene in water, total polycyclic aromatic hydrocarbons (PAH) in bottom sediment, total DDT substrates in bottom sediment and polychlorinated biphenyls (PCB) in bottom sediment.

These parameters were selected for several reasons. Fluoranthene is a ubiquitous polycyclic aromatic hydrocarbon that has been reported in surface water and wet precipitation in the region and though naturally occurring would provide an indication of localized source inputs. Total PAH's in bottom sediment would help to validate fluoranthene observations. PCB's and DDT are both man made and would be directly indicative of industrial and agricultural anthropogenic inputs respectively. The use of bottom sediment observations was indicated due to tendency for these two contaminants and several of the high molecular weight PAH's to be sorbed to sediment particles.

The first step in integrating the observed toxic data with the hypothesis map was to simply plot the data on a map of the Atlantic Region. SPANS is unable to distinguish between point attributes, however, and is limited to just plotting their locations. That is, SPANS will plot the locations where toxic data were observed but cannot distinguish between the various concentrations at each of

these points. To overcome this barrier, the Potential Mapping function was invoked to assign a five kilometre sphere around each of the observations. A five kilometre sphere was selected simply because this size would make the resultant maps easier to view. The spheres were then recolored according to their relative concentrations.

Hanna (1987) used the approach of setting various concentration ranges as indicators of "very high" to "low" levels of contamination. Within this framework the data somewhat dictated what the ranges should have been. As an estimate, a given range difference was between .5 and 1 order of magnitude. Unfortunately no guidelines for freshwater aquatic life exist for DDT, total PAH or PCB in bottom sediments nor for fluoranthene in water (CCREM 1987). As with the potential maps, the use of the terminology "very high, high, moderate, and low" are relative to the region and to the Water Quality Branch data. Also observation ranges represent median values. Thus there were single values recorded in excess of and below any specified median.

The final stage in proving the hypothesis was to determine the relationship between the observed levels and the hypothesis map - or which observations fell where. To accomplish this, the Points Modeling function of SPANS was invoked and the tynumbers from the hypothesis map were appended to each of the points in the toxic contaminant files. This generated point files containing the observed toxic concentration and the associated hypothesis map locations for each record. These files were then copied into the existing Dbase toxic data files for manipulation.

Using Dbase, each toxic data file was accessed and a simple counting command was executed. By counting the frequency of corresponding observed and predicted levels of

toxic contaminants the relationship between the hypothesis map and empirical data may be explained.

Identification of Sensitive Areas

The third stated objective, after generation and validation of the hypothesis map, was to illustrate how SPANS generated maps could be useful as a tool in the planning and design of monitoring programs. As the hypothesis map illustrates and ranks areas of potential input, correspondingly areas that are of environmental significance needed to be identified.

To accomplish this task it was decided to use known federally administered areas and proposed ecological reserves as examples. Canadian Wildlife Service provided location information for National Wildlife Areas and Migratory Bird Sanctuaries in the Atlantic area (A. Smith, 1988). The national wildlife areas are primarily wetlands of importance to waterfowl while the migratory bird sanctuaries, of which there are 12 in the region, provide protection to migratory birds by prohibiting hunting and the disturbing of birds (Eaton et al. 1986).

Ecological reserves were selected as representative areas containing ecosystems identified by the International Biological Program as being significant due to diversity of flora and fauna and for the conservation of natural areas (Eaton et al. 1986). There were in excess of 170 ecological reserves identified in the region but only 8 in New Brunswick and 9 in Newfoundland have been proclaimed and protected. Several other sites lie in national parks or other protected areas (Beardmore 1985). The New Brunswick Department of Natural Resources (Fitton 1988), and the Nova Scotia Museum (Davis 1988), provided accurate location information for the respective ecological reserves.

All these sites represent areas that are either protected or identified as areas of environmental significance that need to be protected from anthropogenic activities. By importing these data points into SPANS and overlaying them onto the hypothesis map we can illustrate how many sites lie in close proximity to potentially high input sources.

RESULTS AND DISCUSSION

Potential Sources of Toxics Map

The use of SPANS and Dbase III+ permitted the efficient and effective integration of several spatial data sets. If traditional methods had been employed, this integration might easily have taken six to ten times as long to complete. By conjugating land use, population density, and industry location data with various matrices, maps indicating the potential levels of toxic contaminants through the Atlantic Region were successfully created.

Two maps were generated that are of specific application to the Water Quality Branch. The first, Potential Sources of Pesticides (Figure 4) delineates pesticide potential as a function of agricultural activity. The second, Potential Sources of Toxics (Figure 6) incorporates anthropogenic and demographic factors that represent other toxic organic and inorganic environmental contaminants. It should be pointed out that Figures 1 through 12 were generated on a Tectronics printer using a black-and-white driver. This was done in order to keep reproduction costs within reason. Normally a color printer is utilized resulting in better color resolution and contrast. A larger number of groupings may be utilized with color printing also.

As with any hypothesis there were certain assumptions that were made during the generation of the hypothesis map that must be addressed. It was assumed that areas under forest usage represented areas of minimal anthropogenic activity as related to potential toxic chemical inputs. However it is well documented that the spruce budworm abatement program inputs fenitrothion and *Bacillus Thuringensis* (BT) to forested areas of New Brunswick and Newfoundland. Also forest spray operations carried out on silviculture

plantations were not included. In addition, the use of the "Low, Moderate, High, and Very High" nomenclature was employed solely to keep matrices simple and to provide a relative potential for the region.

As a result of data conjugation one can see in Figure 6 that the areas of greatest potential lie along the inhabited coastlines and principal waterways of the region. Halifax, Sydney and Saint John stand out as a result of the industry and shipping associated with each location while most of Prince Edward Island, Cumberland County and the Annapolis Valley of Nova Scotia and the Saint John River Valley of New Brunswick show up as "High" areas because of the associated agriculture and populations. Areas of "Moderate and Low" toxic potential can be seen along less populated coastal locations and in the interior of each province excluding Prince Edward Island. Areas designated as "Unclassified" or "No data available" are due to information gaps in one of the data sets used to generate the hypothesis map. Canadian Forces Base Gaagetown, Kejimikujik National Park, Cape Breton Highlands National Park and the Great Northern Peninsula of Newfoundland are the four locations where major data gaps existed.

The areal analysis capability of SPANS was explored by calculating the area of the region that fell into each potential input category. The result of this areal analysis is summarized in Table 5. It can be seen that 9.69 percent of the region falls into the "Very High" and "High" category, 20.88 percent falls into "Moderate" potential and 62.77 percent is in the "Low" potential input category. When viewing this table it is important to keep in mind the various limitations described earlier as well as the relative nature of the various potential input categories.

The hypothesis map should not be used solely as an empirical formula but rather in a qualitative context to identify areas where the potential of environmental contamination may occur.

Observed Toxic Chemical Data

The second stated objective was to verify the hypothesis by carrying out an examination of the relationship between the hypothesis map and actual Water Quality Branch measurements of environmental contaminants. Four Water Quality data sets were inputted: fluoranthene in surface water, total DDT substrates in bottom sediment, total polyaromatic hydrocarbons in bottom sediment and, polychlorinated biphenyls in bottom sediment. The median observations for each group between 1980 and 1987 are given in Figures 7 through 10 respectively. Each point represents a metering location and the symbol is indicative of the median value for the location. These figures had to be letraset as black-and-white printing would not illustrate the various chemical concentrations as well as color printing. Normally a 2 km sphere of a specific color would indicate a median concentration range.

As Water Quality Branch data were in the form of point information, it was impossible to perform a direct areal analysis. However, the use of frequency counting would provide a measure of the validity of the hypothesis map. Observed concentrations of each toxic substance were superimposed upon the hypothesis map and a frequency count carried out.

Although certain anomalies exist, WQB data indicate a definite correlation between the observed toxic levels and the hypothesis map. Eight of the eleven observations of PAH ranked "Very High" or "High" also occurred within polygons ranked "Very High" or "High" on the hypothesis map. A similar

pattern was observed for the other three contaminants (12 of 15 Fluoranthene observations, 16 of 20 DDT observations and 7 of 9 PCB observations). In other words 78% of all observations ranked "Very High" or "High" occurred in areas similarly ranked on the hypothesis map. The "Very High" and "High" median observations represent the highest median concentrations observed for the parameters of interest by the Branch. Though there was a 78% correlation between the hypothesis map and Branch data, there were some anomalies in the interior of New Brunswick and the southwest tip of Newfoundland. Because of the time frame within which the samples were collected (1980-1987) they are subject not only to spatial variability but also temporal variability as well. The nature of the chemicals themselves can explain some anomalies. DDT though not used anymore, was used as an insecticide in forestry and agriculture while PCBs were subject to industrial applications. This explains why the Annapolis Valley shows mostly less than detection limit values for PCB but has a wide range (low to very high) of DDT observations. This example illustrates interpretation limitations that must be kept in mind.

Areas identified as low potential input may have anomalously high observations due to industry or land use activities that are not included in the data bases used to generate the hypothesis map. This indicates the importance of having up to date data bases.

Four perfect correlations were noted, wherein the observed levels of "High or Very High" matched predicted levels. The positive correlations indicated by the data supports the hypothesis map as fairly accurate in predicting relative potential levels of toxic contaminants throughout the Atlantic provinces.

The validity of the pesticide and toxics maps has also been tested by the use of Water Quality Branch nutrient information. Part of Branch investigations into acid rain and long range transport of airborne pollutants has recently been incorporated into SPANS to ascertain localized versus long range transport susceptibility (Howell, 1988). Nutrient maps, particularly phosphorus, bore a resemblance to the potential sources of pesticides map (Figure 4). A two map correlation indicated an 80 percent agreement between areas of "Very High and High" potential pesticide input and higher eutrophic states. The importance of this correlation is not only the support of the pesticides hypothesis map but more importantly an indication that pesticide and nutrient processes are not independent of each other but are closely related due to land use. Farmers who are willing to expend resources in crop protection (pesticides) are very apt to also use fertilizers (nutrients) to improve soil fertility and crop yields.

The support of the hypothesis map was much stronger when the nutrient data were used as there were in excess of 800 metering locations on a regional basis.

An analysis of locational and areal data in a study of this size offers many possibilities to the researcher. The goal of any spatial analysis is to identify the causes or processes that have contributed to the existence of an observed phenomenon. This study, however, is not intended to be an exhaustive exploration of the distribution of toxic chemical loads throughout the Atlantic provinces. It represents only a beginning. As such, the multivariate correlation and regression tools available to the geographer have not been employed in this work.

Perhaps the most restrictive limitation in any research involves the availability and quality of data. In the absence of relevant and up-to-date information, the development of

numerically valid conclusions can be seriously impeded. Agriculture and forestry use data for instance, are at least fifteen years old, while the population statistics used are from the year 1981. Within spatial analysis contexts, data regarding the observations of toxics are both quantitatively and qualitatively impaired. In total, only 274 metering locations yielded toxic data throughout the four provinces. One glance at the maps illustrating observed levels of individual toxic substances (PAHs, DDTs, PCBs and Fluoranthene) reveals the insufficiency of data. Though the observed levels of contaminants are scientifically valid the existence of only 274 metering locations does not provide for a rigorous testing of the hypothesis. The location and frequency of sampling encountered is as a result of the programs and projects under which the samples were collected. Some metering locations are associated with specific toxic chemical surveys, basin studies or the municipal drinking water sources toxic chemical survey. The over 800 nutrient metering locations provided a broader data base for hypothesis testing.

Moreover, while every effort has been made to ensure the integrity of these data, levels of observed toxicants are influenced by many factors. The effects of temperature, weather conditions, biological or chemical degradation, transport rates, chemical volatilization, and sorption rates to sediment and soil are some of the elements which influence the observed level of a toxic in the environment. These, added to technological detection limits, clearly indicate that obtaining reliable information is not easy.

Additionally, the spheres of influence drawn around known industrial point sources to indicate "Very High" relative levels of potential toxic input are based solely on educated estimates. No formal consideration of prevailing wind

directions, soil types, etc., have been made in establishing their size.

Applications to Network Design

The last objective was to illustrate how SPANS and its resultant hypothesis map could be of use in the design of water quality network or site prioritization within project management. The potential sources of pesticides map (Figure 4) and the potential source of toxics map (Figure 6) clearly present areas that would be influenced by agrochemicals and total toxics respectively. This type of information is of use to those who are not familiar with the Atlantic Region. They also reflect two Water Quality Branch project areas.

Figures 11 and 12 illustrate Canadian Wildlife Service Migratory Bird Sanctuaries/National Wildlife Areas, and Ecological Reserves in New Brunswick/Nova Scotia respectively. In each case a 10 kilometer sphere of influence was drawn around the geographic center of the locale and displayed over the toxics map (Figure 6). This size sphere was chosen in order to illustrate what areas of environmental significance lie in close proximity to areas of potential pesticide and toxic chemical input. The Tantramar Marsh area between New Brunswick and Nova Scotia contains wetlands and marshes that are close to industry in and around Amherst, Nova Scotia. Several ecological reserves can be seen near Minto, New Brunswick and two Federally administered areas lie in the Annapolis Valley of Nova Scotia. It is also clear that several identified areas lie within the "Low" toxic input potential areas.

The potmapping function of SPANS was invoked to generate 10 kilometre spheres around each federal area and ecological reserve. The two resultant maps were, subsequently imposed upon the potential sources of toxics map and an areal analysis

carried out on each group. On a regional basis it was found that within the 10 kilometre sphere around Canadian Wildlife Service (CWS) administrative areas 35 percent of the area fell into the "Very high" and "High" categories while 63 percent fell into the "Moderate" and "Low" areas. A similar analysis for the ecological reserves in New-Brunswick and Nova Scotia indicated that 11.3 percent were in the "Very High" and "High" categories while 84.6 percent were in the "Moderate" and "Low" categories. The differences in the areal analyses are most likely due to the specialized nature of the CWS sites versus the holistic criteria of the International Biological Program.

A simple visual analysis shows which locales would be more suitable as background locations and which are in greater danger of environmental degradation. Such an exercise would be useful in order to efficiently allocate departmental resources in the project planning phase.

Another application may be seen in Figures 7 through 10 which illustrate the location and median observation for four chemicals. It can be seen that there has generally been wide sampling coverage for fluoranthene in water (Figure 7) but that DDT sampling in sediment (Figure 8) has centered in western New Brunswick and the Annapolis Valley of Nova Scotia. Figure 4 shows that there are several other areas of the region that are subject to potential agricultural inputs that may warrant further investigation. This analysis does not denigrate Water Quality Branch activities but illustrates analytical observations which stemmed from program specific toxic chemical surveys. However, it does illustrate how past activities can be inputted and used to plan future endeavours.

The various base maps used in the generation of the hypothesis map are also of use in project design. Ecodistrict information, land use, land capability, and population density, may be determining factors in site selection and

priorization. As more data bases are geo-referenced the greater the ability to conjugate information will be. Data pertaining to bedrock geology, aquifer depth, landfill location, bird colonies, or secondary industry would be of use to natural resource managers.

SPANS allows the generation of hypotheses and models which may be tested by using known data or verified by actual field monitoring. The use of historical data may be used as an initial economical means to test a hypothesis which may then be followed up with a specific monitoring program.

CONCLUSIONS

Two maps were generated through the conjugation of land use, land capability, industrial location, and demographic data bases. The Potential Sources of Pesticides map illustrates the potential sources of agricultural pesticides, while the Potential Sources of Toxics map illustrates all known agricultural, industrial, and population factors. A relative scale ranging from "Very High" potential to "Low" potential was employed to rank contaminant potential on a regional basis. An areal analysis of this map indicated that approximately 10 percent of the region fell into the "Very High" and "High" categories.

An examination of empirical data confirmed the general accuracy of this map. Of the 55 observations of toxic contaminants (PAH including Fluoranthene, DDT, and PCB) ranked "High" and "Very High", 78% (43) are located in areas ranked "High" and "Very High" on the hypothesis map. Additionally, the strong correlation between potential pesticide input and nutrient levels supported the validity of the hypothesis map.

Monitoring networks for individual toxic contaminants may be enhanced by following the approach of this study. The occurrence of a toxic chemical in the environment is a function of many things, but by converting information relevant to a specific toxin (contributing industries, land use, etc.) into maps and conjugating them together with matrix overlays, accurate predictive maps may be created. Making use of these maps (by identifying "hot-spots" etc.) will assist in selecting monitoring locations by eliminating some of the guesswork currently involved.

RECOMMENDATIONS

The original hypothesis map could be further refined with the integration of additional data. Prevailing wind information could be used to investigate the possibility of atmospheric transport, the location of land fill sites, additional industry locations, soil type information and subsurface geological data could all be incorporated to improve the data base and to broaden the predictive reliability of a hypothesis map.

The preparation of this report entailed the downloading into SPANS of various CLI data sets, Water Quality Branch observations, industrial locations, population data, and the locations of various ecological reserves and wildlife areas. These, combined with subsequent conjugation have resulted in a significant amount of data residing at the Water Quality Branch. To avoid duplication regional users of SPANS should cooperate as much as possible in data exchanges to enhance respective information bases.

ACKNOWLEDGEMENTS

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Tom Pollock and Geoff Howell must be thanked for their reviews and suggestions throughout and Louise Boulter thanked for her patience in typing the manuscript.

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FIGURE 1

Preparation of the Hypothesis Map

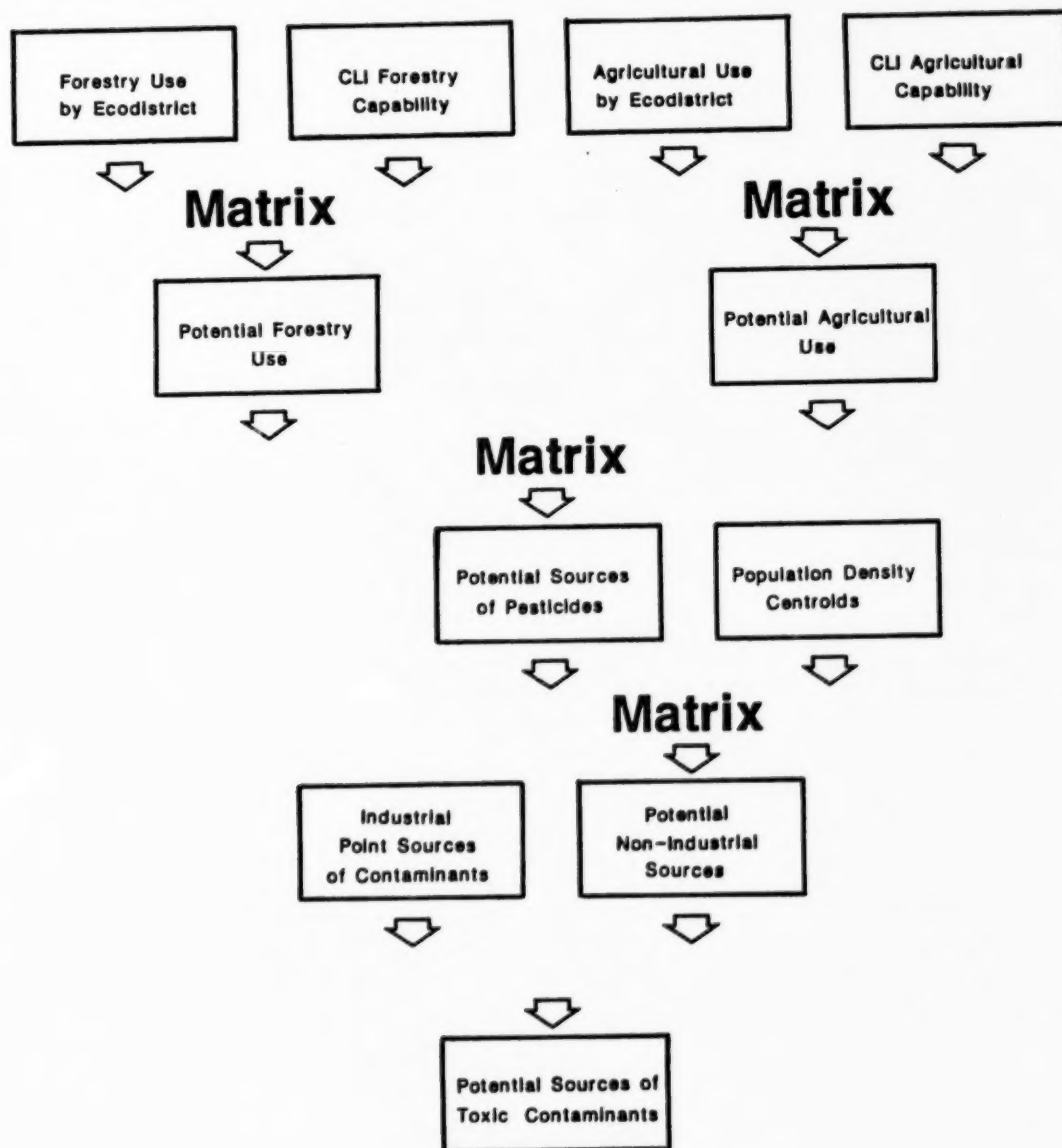


FIGURE 2: POTENTIAL FORESTRY USE

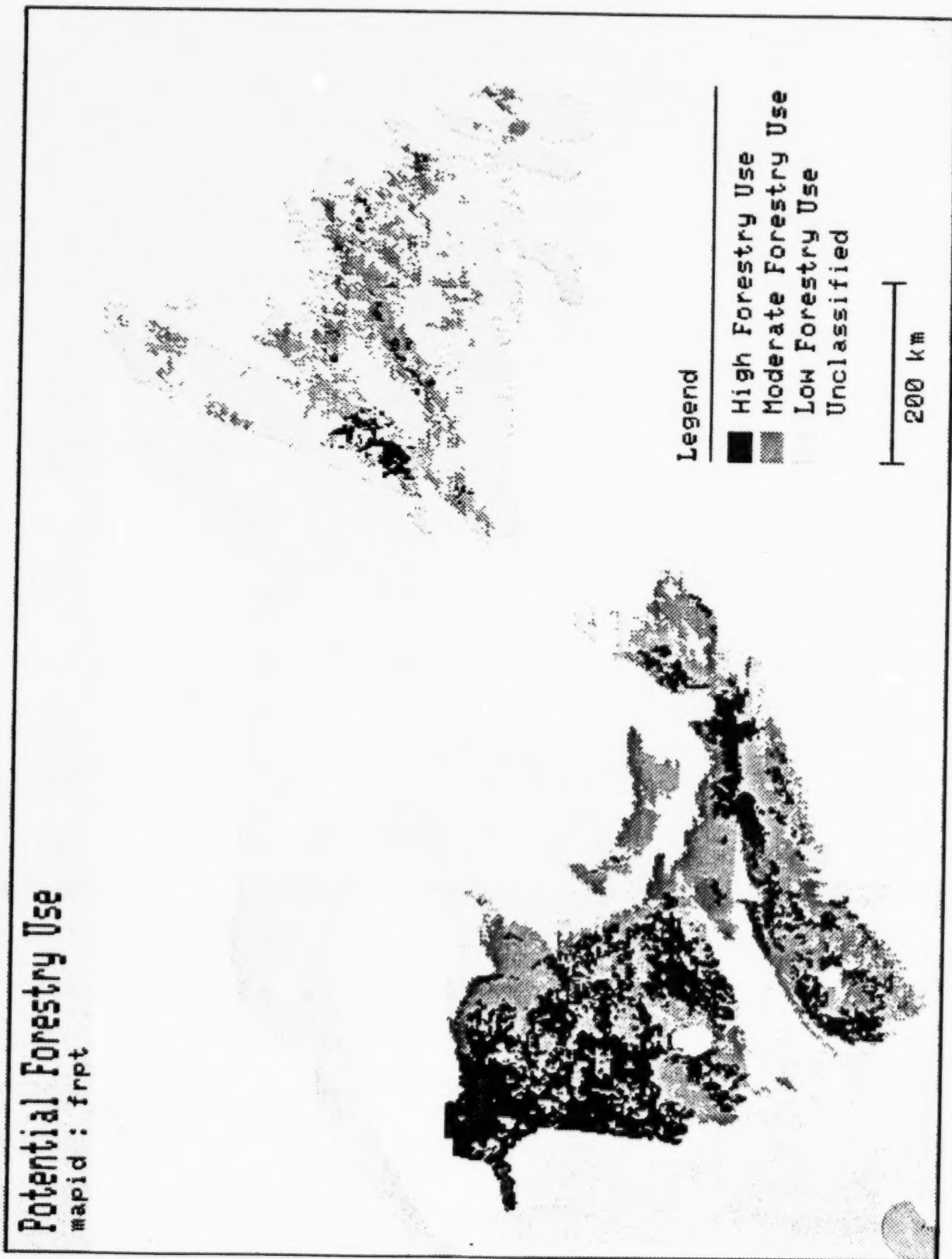


FIGURE 3: POTENTIAL AGRICULTURAL USE

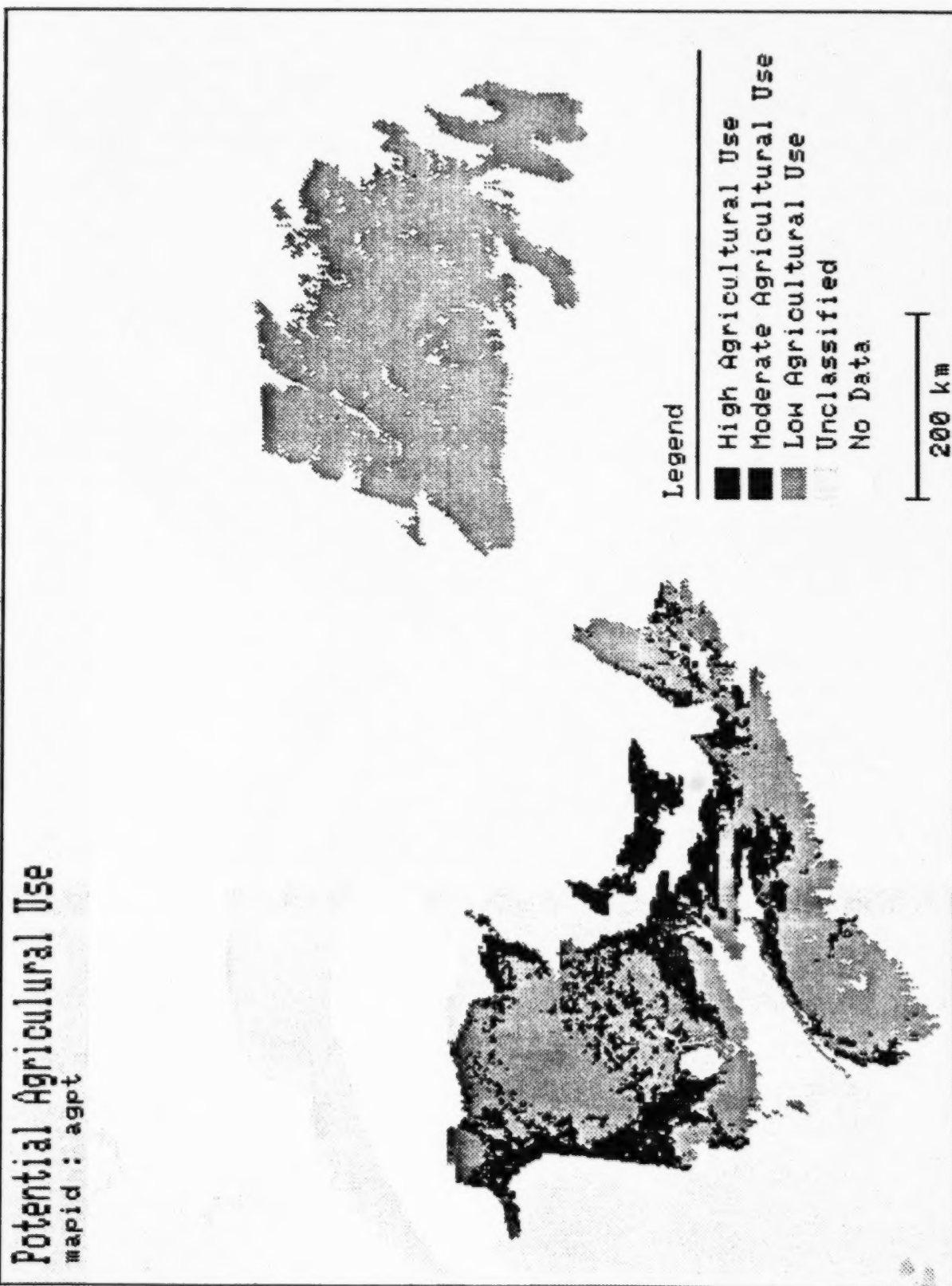


FIGURE 4: POTENTIAL SOURCES OF PESTICIDES

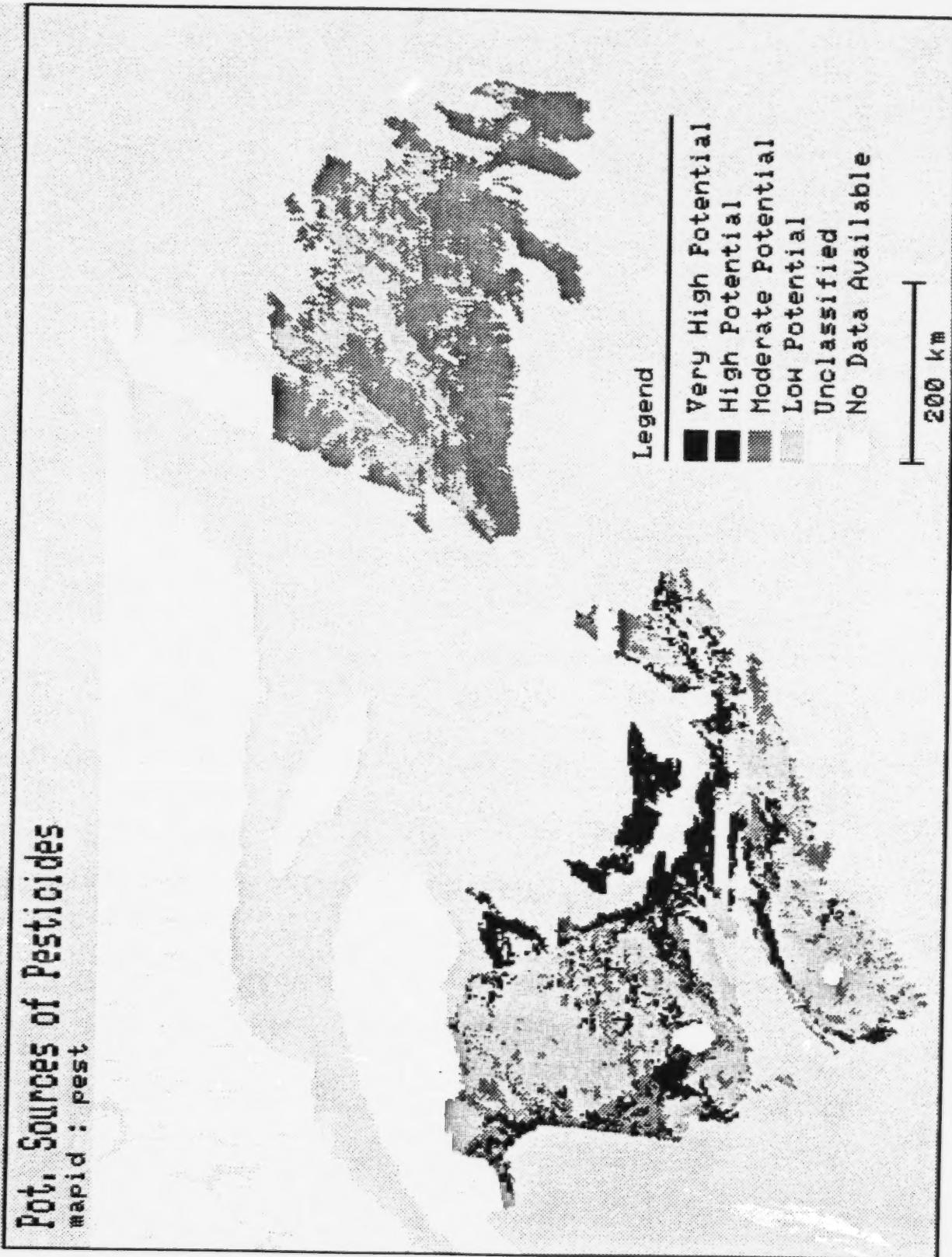


FIGURE 5: INDUSTRIAL POINT SOURCES

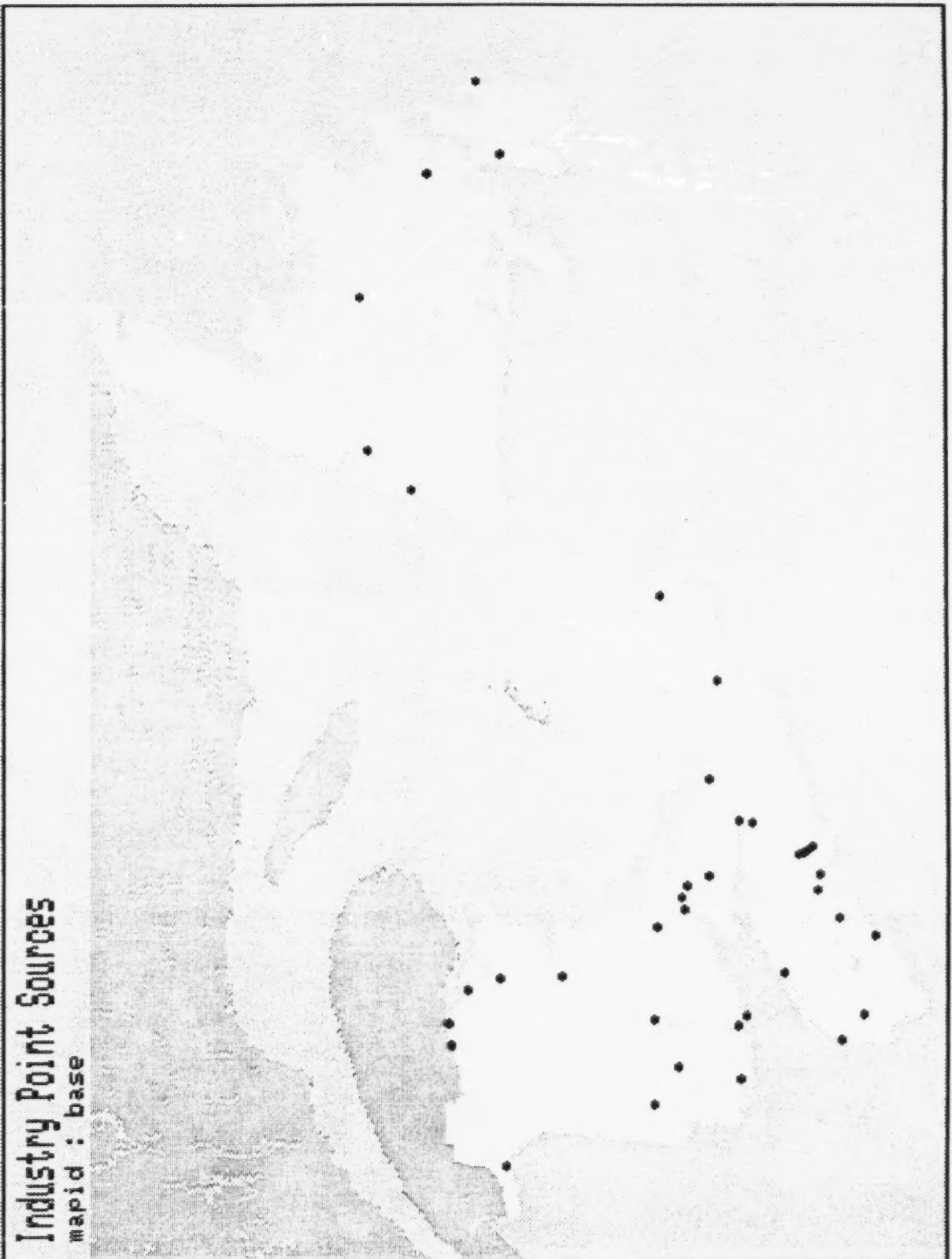


FIGURE 6: POTENTIAL SOURCES OF TOXIC CONTAMINANTS

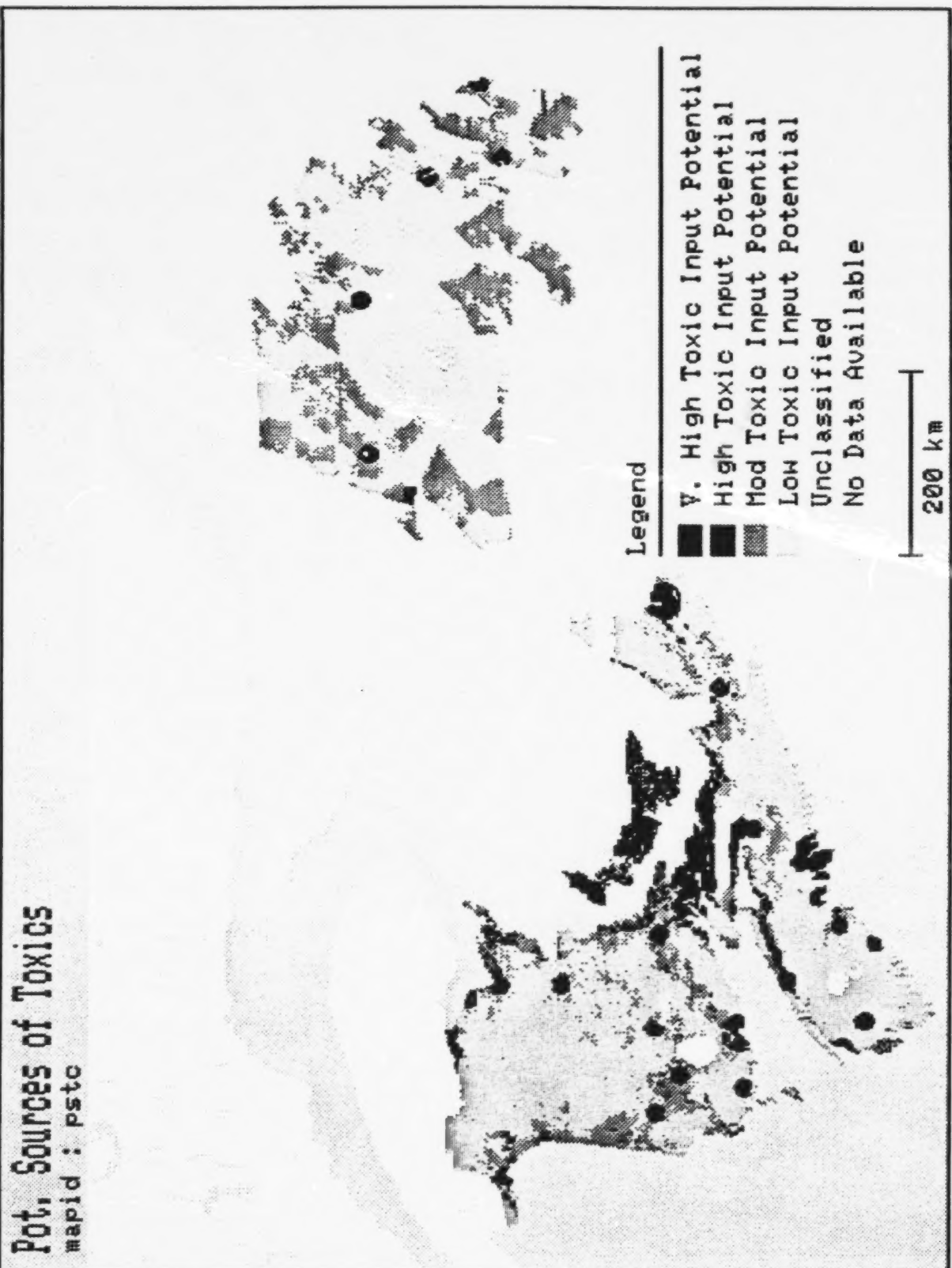


FIGURE 7: OBSERVED LEVELS OF FLUORANTHENE

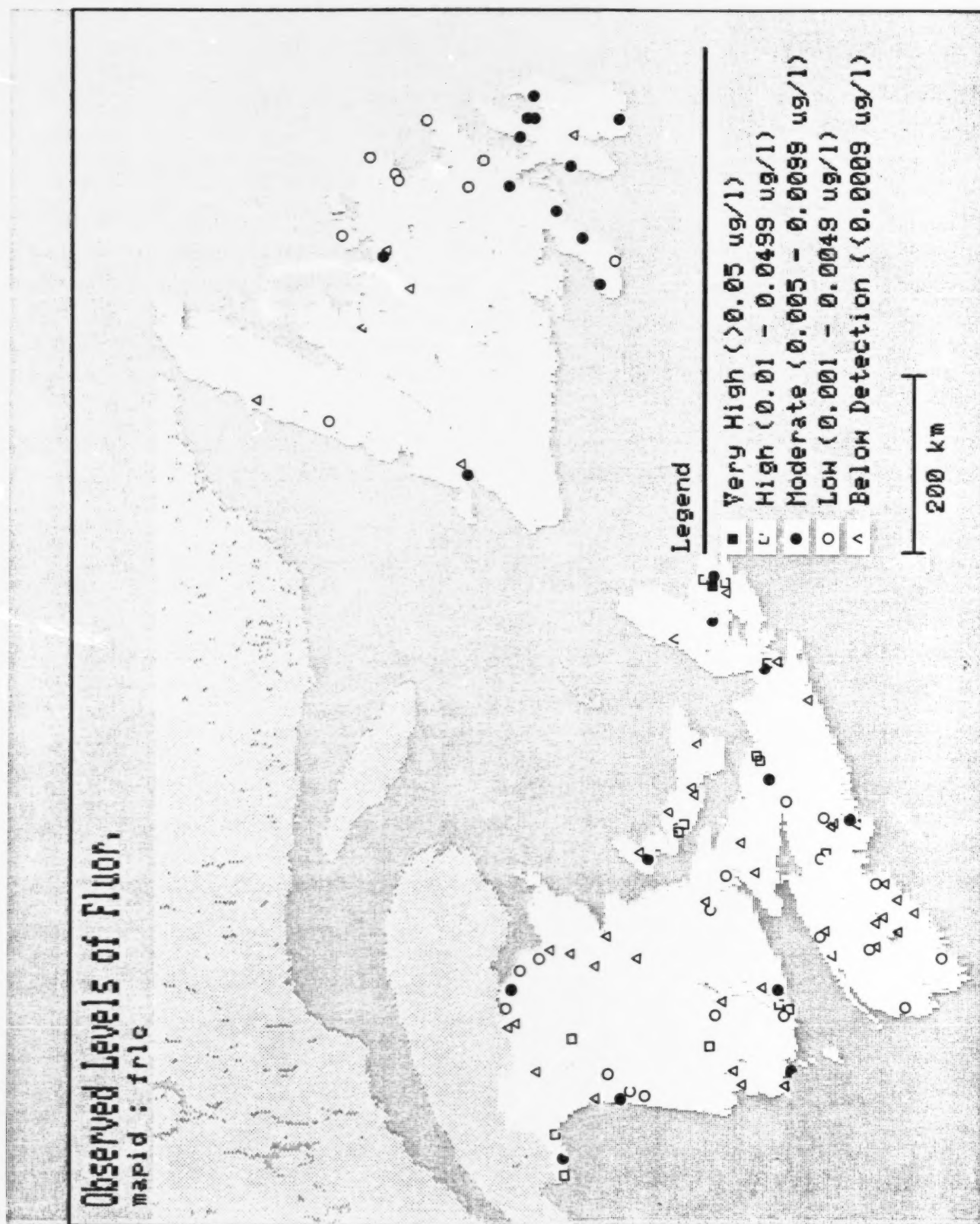


FIGURE 8: OBSERVED LEVELS OF DDT

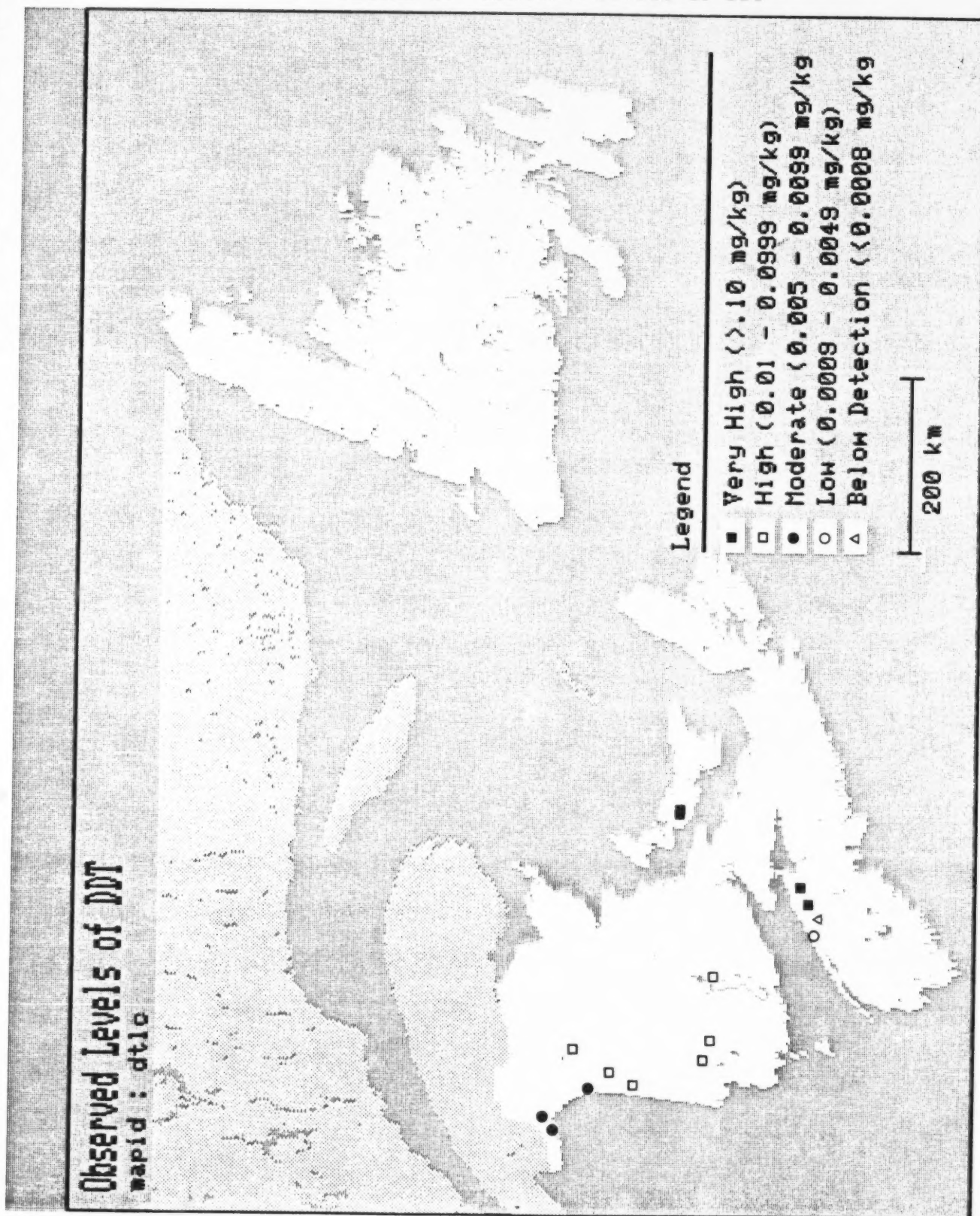


FIGURE 9: OBSERVED LEVELS OF PAH

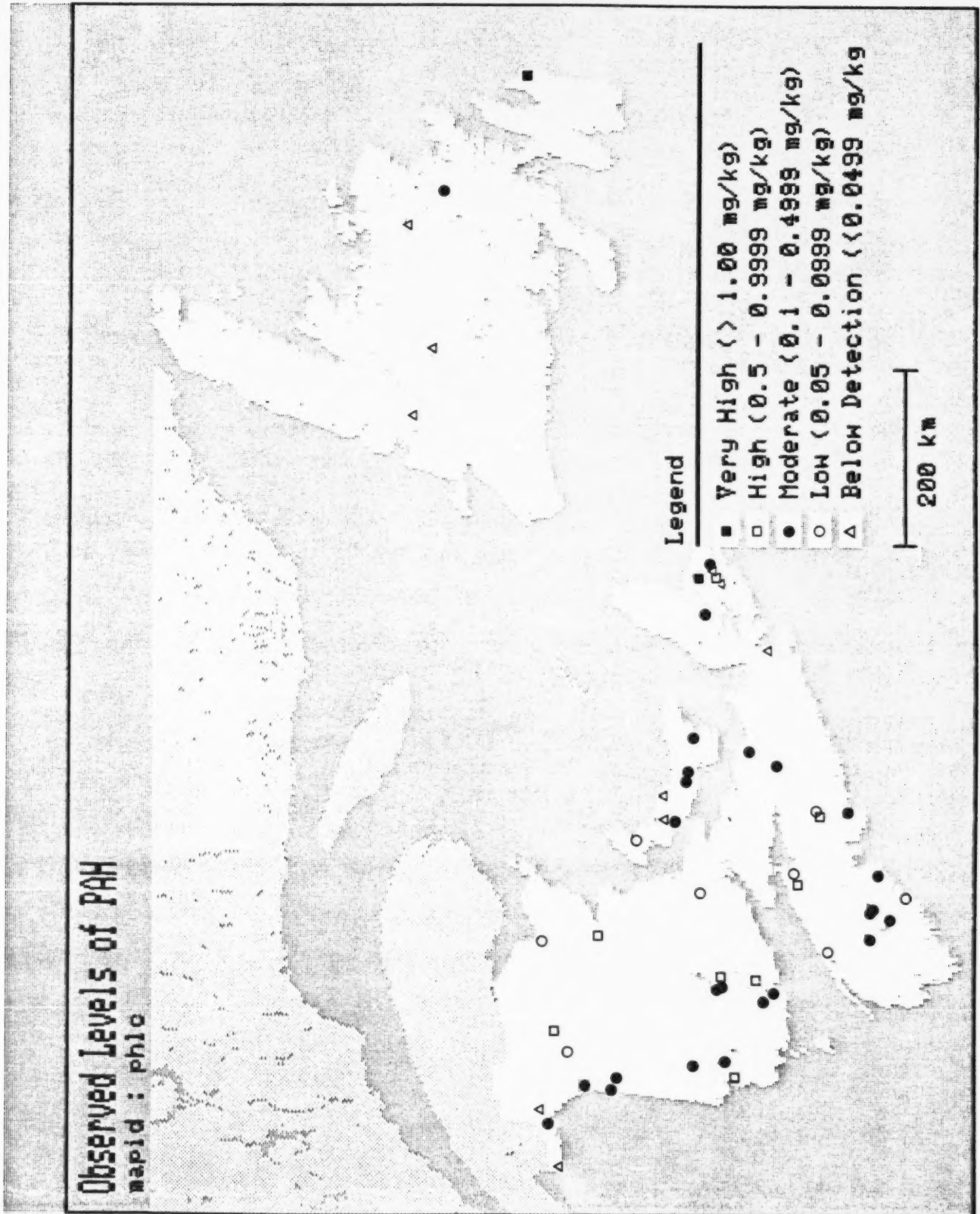


FIGURE 10: OBSERVED LEVELS OF PCB

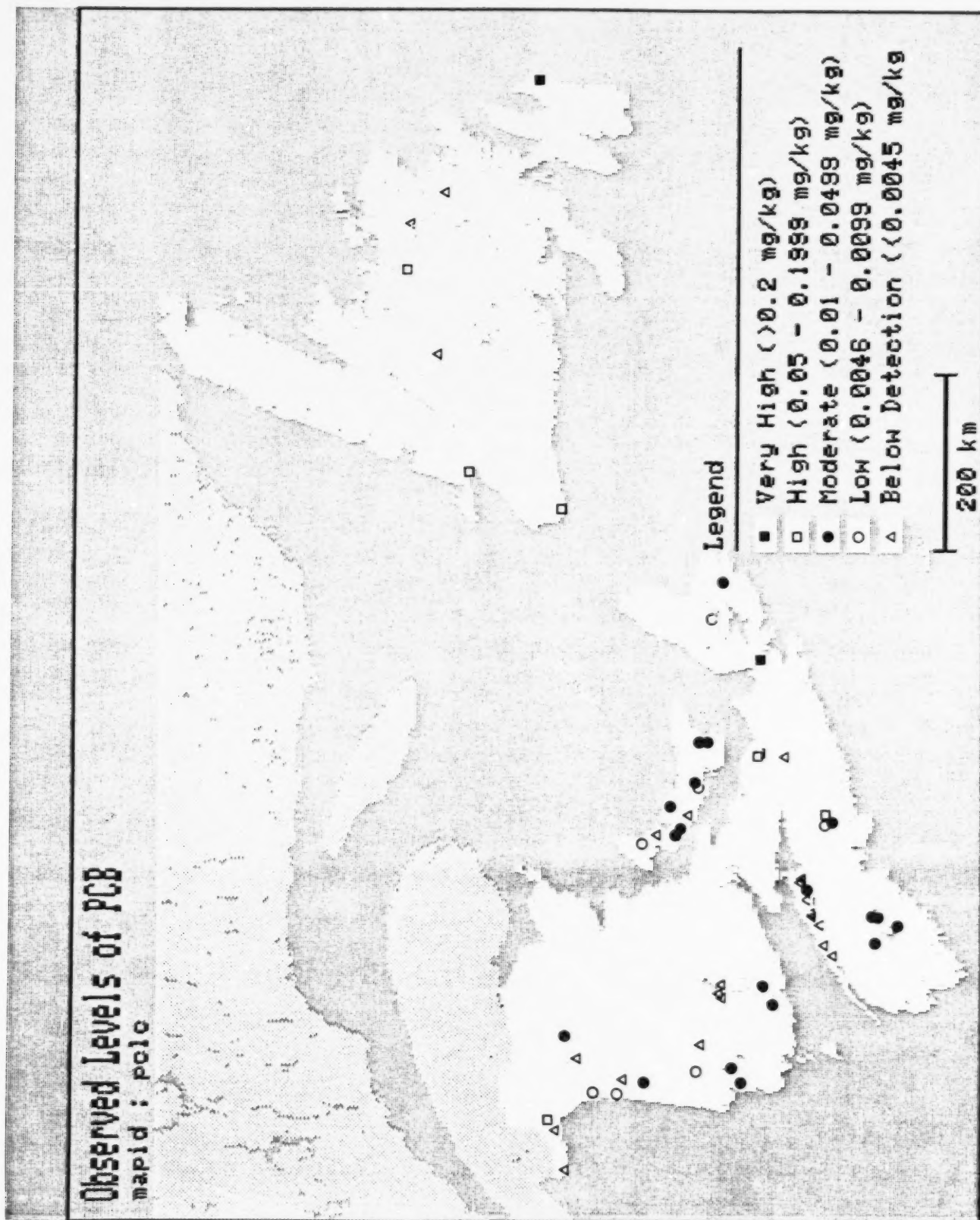


FIGURE 11: CANADIAN WILDLIFE SERVICE MANAGED AREAS

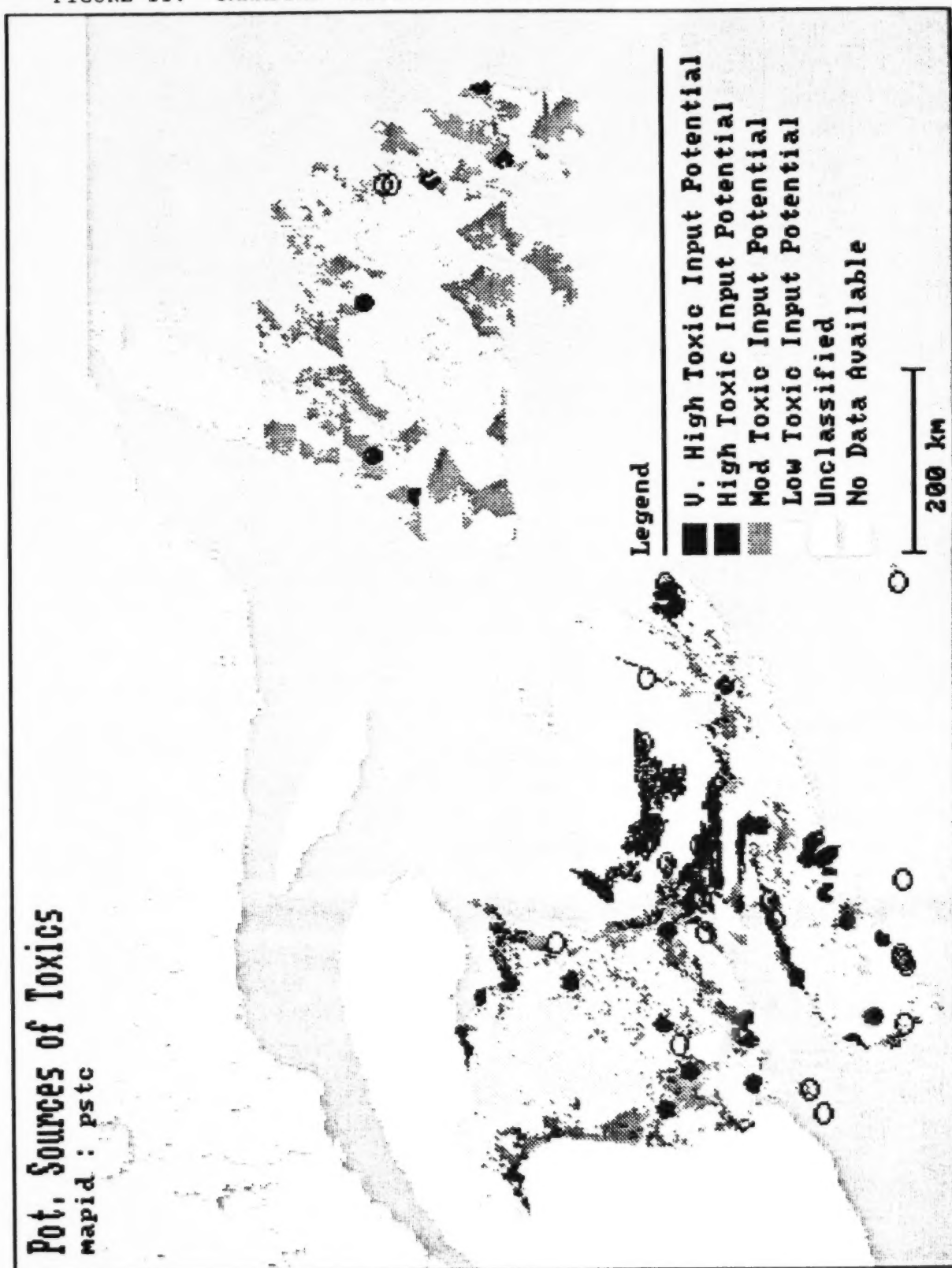


FIGURE 12: IBP ECOLOGICAL RESERVES

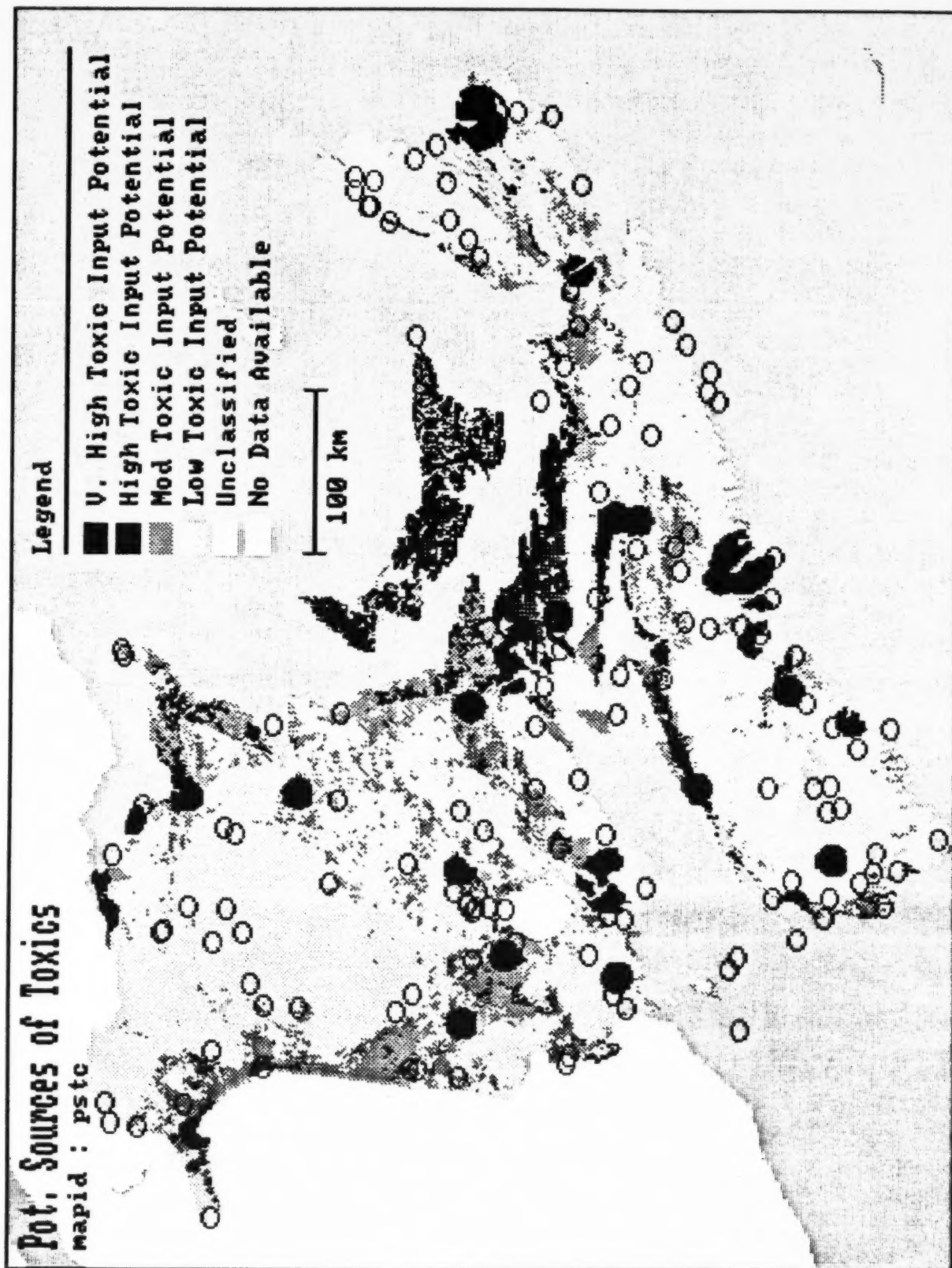


TABLE 1
CLASSIFICATION OF OBSERVED TOXICANTS

Polycyclical Aromatic Hydrocarbons

Less than	0.0499	mg/kg	=	Below Detection Limit
0.05 =	0.0999	mg/kg	=	Low
0.10 =	0.4999	mg/kg	=	Moderate
0.50 =	0.9999	mg/kg	=	High
Greater than	1.00	mg/kg	=	Very High

Fluoranthene

Less than	0.0009	µg/L	=	Below Detection Limit
0.001 =	0.0049	µg/L	=	Low
0.005 =	0.0099	µg/L	=	Moderate
0.01 =	0.0499	µg/L	=	High
Greater than	0.05	µg/L	=	Very High

PCB

Less than	0.0045	mg/kg	=	Below Detection Limit
0.0046 =	0.0099	mg/kg	=	Low
0.01 =	0.0499	mg/kg	=	Moderate
0.05 =	0.1999	mg/kg	=	High
Greater than	0.2	mg/kg	=	Very High

DDT

Less than	0.0008	mg/kg	=	Below Detection Limit
0.0009 =	0.0049	mg/kg	=	Low
0.005 =	0.0099	mg/kg	=	Moderate
0.01 =	0.0999	mg/kg	=	High
Greater than	0.01	mg/kg	=	Very High

TABLE 2
POTENTIAL USE MATRIX

		Land use				where,
		High	Mod.	Low	No Data	
Land	2	1	1	2	5	1=High Use
Capability	3	1	1	2	5	2=Moderate Use
Classes	4	1	2	3	5	3=Low Use
	5	2	2	3	5	4=Unclassified
	6	3	3	3	5	5=No Data
	7	3	3	3	5	
Organic		3	3	3	5	
No values		4	4	4	5	

TABLE 3

POTENTIAL SOURCES OF PESTICIDES MATRIX

Potential Forestry Use

[illegible]

TABLE 4

POTENTIAL NON-INDUSTRIAL SOURCES MATRIX

Potential Sources of Pesticides

	V.					No	
	High	High	Mod.	Low	Un-	Data	where,
Population	High	1	2	3	Class	6	1=Very High
Density	Mod.	2	3	4	5	6	2=High
	Low	2	3	4	5	6	3=Moderate
							4=Low
							5=Unclassified
							6=No Data

TABLE 5

AREA ANALYSIS ON HYPOTHESIS MAP

	AREA (%)	COMMULATIVE (%)
Very High Toxic Input Potential	4.82	4.82
High Toxic Input Potential	4.87	9.69
Moderate Toxic Input Potential	20.88	30.57
Low Toxic Input Potential	62.77	93.34
Unclassified	1.44	94.78
No Data	<u>5.22</u>	<u>100.00</u>
	100.00	100.00